SOME RESULTS OF THE EXPERIMENTS

CARRIED OUT IN THE INTERPLANETARY SPACE

BY MEANS OF CHARGED PARTICLE TRAPS ON

SOVIET COSMIC ROCKETS

by

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(Nekotoryye rezul'taty opyoov provedennykh v mezhplanetnom
prostranstve s pomoshch'yu lovushek zrryazhennykh
na Sovetskikh kosmicheskikh raketakh)

Experiments with three-electrode traps were conducted to-
date on all Soviet cosmic rockets (including the Venus probe, laun-
ched on 12 February 1961) to obtain informations on the ionized
gas in the space surrounding the rockets at time of their flight
and on fluxes of charged particles with comparatively low energies,
lying below the limits of sensitivity of indicators used for the
registration of cosmic rays. The study of the currents induced by
charged particles hitting the traps at various portions of rocket's
trajectory, and particularly the comparison of currents registered
simultaneously in traps with different potentials of their exterior
grids, disposed at random, led to the detection of the outermost
radiation belt surrounding the Earth. It also allowed to register
for the first time solar corpuscular streams in the interplanetary
space, outside the geomagnetic field, and estimate the possible
concentration of the assumingly existing interplanetary ionized gas.

1. SOME GENERAL DATA ON THE SETUP OF EXPERIMENTS

The three-electrode traps used in all experiments with
charged particle traps have been described in [1]. The traps were

installed in containers and interplanetary stations (AIS) sepa-
rating from the bearing rocket. The containers of the first three
cosmic rockets did not have compulsory orientation at portions of
the trajectory over which telemetring of information took place
(they were therefore freely-rotating). The AIS of the fourth cosmic
rocket was specifically oriented toward the Sun, and during radio-
telemetric data transmission the normals to traps' collectors coin-
cided with the direction toward the Sun.

Fig.1 shows the layout of traps installed on the first
cosmic rocket, launched on 2 January 1959. In that trap a spherical
inner antiphotoelectron grid was applied. To reduce significantly
the reverse photocurrent created by photoelectron emission from the
inner grid, a flat inner grid, substantially less dense than the
first variant, was applied in the traps of the container of the
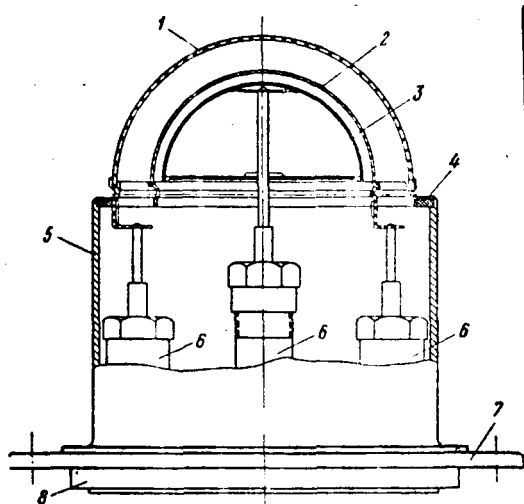2nd cosmic rocket launched toward the Moon on 12 September 1959.

Fig.1. Trap installed on the 1st
cosmic rocket.
1 — outer grid (Ni); 2 — inner grid
(Ni); 3 — collector (Ni); 4 —

This kind of trap is presented
in Fig.2. The same construction
was utilized on the third cos-
mic rocket launched on 4 October
1959. The trap's construction
was alleviated in the 4th cosmic
rocket (Venus probe) launched on
12 February 1961, while the
inner grid was made still less
dense, for further decrease of
the reverse photocurrent. In
all cases the structure of the
electric field between the outer
and the inner grids (collecting
the "thermal" ions reaching into
the trap), and the field between

the collector and the inner grid (decelerating the photoelectrons
from the collector) was studied with the aid of electrolysers.

Fig. 3 offers a view of the traps placed in the container of the first cosmic rocket. All the four traps were placed in a single meridional plane. As to the second cosmic rocket, its traps were placed at the summits of a tetrahedron inscribed into a spherical container (the upper half-sphere of the container of the first rocket being somehow turned by 90° relative to the lower half-sphere, Fig. 4). This assured at least one of the trap to be in the shade at any given moment.

Fig. 5 shows the repartition of traps in the 3rd cosmic rocket. Traps in the upper and in the lower half-spheres are disposed perpendicularly to one another's

Fig. 2. Construction of a trap installed on the 2nd cosmic rocket

Designations are the same as in Fig. 1; the inner grid is here made of wolfram; 9— Nickel blende.

planes. Fig. 6 shows the position of the traps in the AIS of the fourth cosmic rocket. As indicated, they are oriented toward the Sun, just as solar batteries are.

Single-type valve amplifiers of small currents were applied in all experiments, as they assured the transmission through the radiotelemetric system of positive as well as negative collector currents.

As a rule, one of the traps had a positive potential relative to the frame ($\varphi_{g2} = +15$ V in the first and second cosmic rockets, $\varphi_{g2} = 25$ V on the third, and $+50$ V on the fourth), inducing a decelerating field for the "thermal" positive ions, but not hindering the passing into that trap of protons from solar corpuscular streams endowed with energies of the order of units and tens of keV.
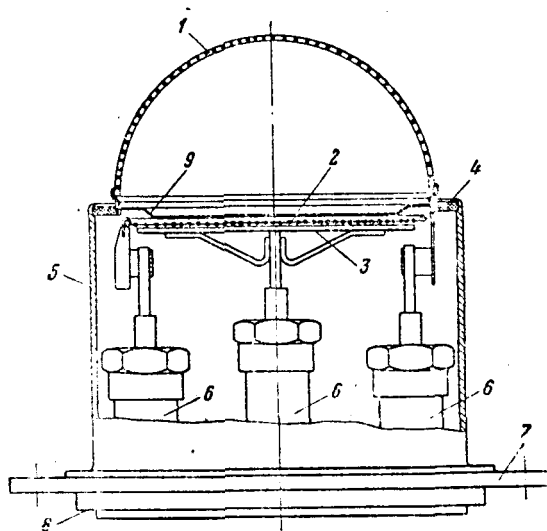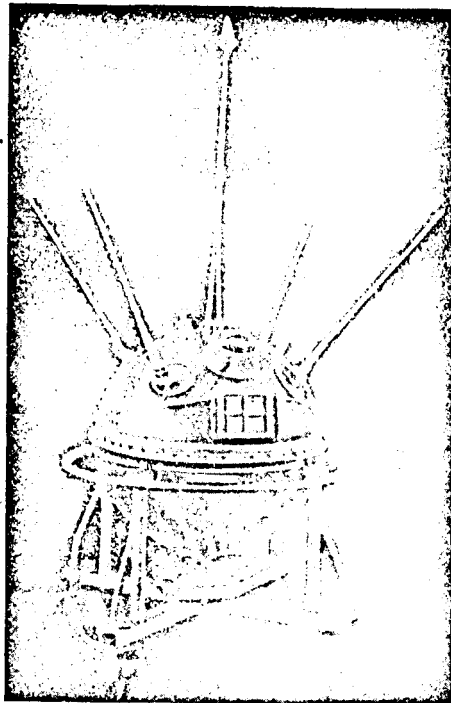
Fig. 3. Exterior view of the container
of the 1st cosmic rocket
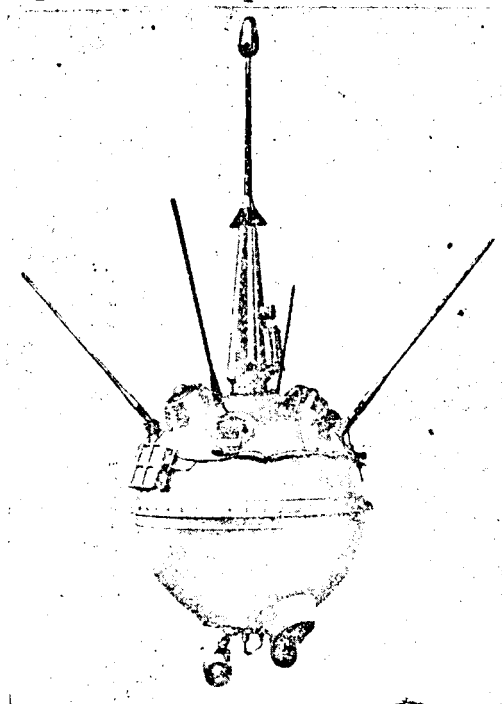
Arrows point to traps installed on the ext.surf.

Fig. 4. Exterior view of the container
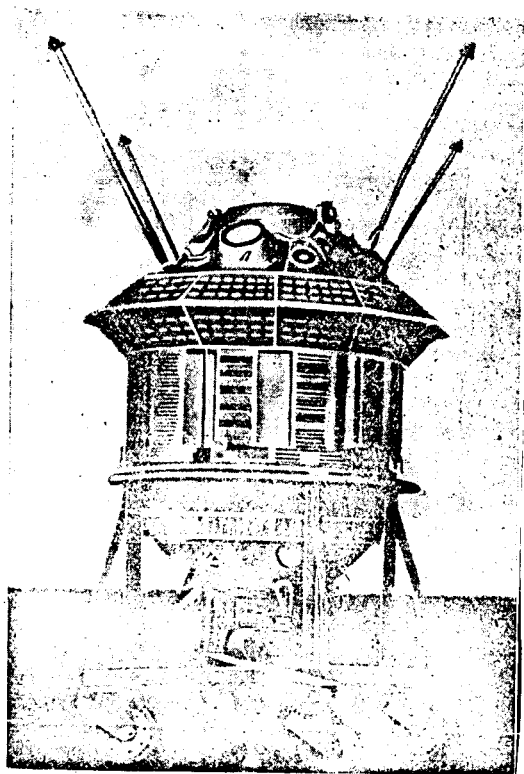of the 2nd cosmic rocket.

Fig. 5. Exterior view of the AIS of
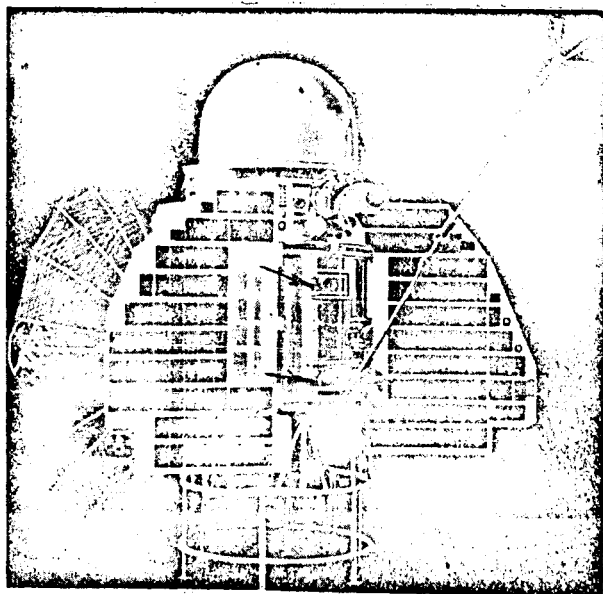the third cosmic rocket.

Fig. 6. Exterior view of the AIS of the
fourth cosmic rocket (Venus probe)
launched on 12 February 1961.

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* AIS for Automatic Interplanetary Station

Of the four traps installed aboard the AIS of the third cosmic rocket, two operated a long time with constant potential in the exterior grids, and two were switched on only for short intervals of time, while the potentials of their exterior grids varied in a "toothed" fashion.

Generally speaking, the collector current in the three-electrode trap, switched on according to the indicated scheme, (Fig. 5 of [1]), may be induced by the following charged particles: positive ions from the outer medium with energies sufficient to overcome the field deceleration created by the exterior grid (in case when its potential induces a decelerating field for the positive ions); fast electrons from the outer medium with energies sufficient to overcome the decelerating field induced by the inner grid of the trap; part of photoelectrons emitted by the inner grid under the effect of solar ultraviolet.

Because of that, the interpretation of collector current measurements may at first sight appear to be ambiguous. However, an appropriate selection of outer grid potentials and a corresponding repartition of traps on the container coupled with attentive examination of the results of measurements, allow to reliably separate certain effects from the others and obtain the required estimates.

2. THE OUTERMOST BELT OF CHARGED PARTICLES SURROUNDING THE EARTH.

Fig. 7 characterizes the results of measurements of collector currents during the flight of the second cosmic rocket at distances from the Earth's surface $R > 20\,000$ km. The curves 1 and 2 respectively are the upper and lower boundary values, within whose limits lay the values of traps' collector currents (with $\varphi_{g2} = -10, -5, 0$ V.). Curve 3 is the upper limit of currents in the trap with $\varphi_{g2} = 15$ V.

The curves are related to two portions of the trajectory: the end of the first trajectory (from 110 000 to 190 000 km) has been dropped, as by the character of its currents it corresponds to the portion from 80 000 to 110 000 km, and the beginning of the second portion (from 245 000 to 330 000 km) has been dropped since by the character of the currents it corresponds to the portion from 330 000 to 370 000 km. The interruption from R ∼ 110 000 km to ∼ 245 000 km was caused by the absence of raio reception over the USSR territory on account of rocket's passing over the Western hemisphere. Inside the indicated intervals the values of the current of each trap oscillate, and their oscillations agree well with rotation periods of the container, determined by data independent from trap readings (for example, by the rotation of radiosignals' polarization plane, received from the container).

Attention must be drawn to the fact that the greatest value of registered negative collector currents at portions R < 50 000 km and R > 75 ⟶ 80 000 km nowhere exceeds $6 \cdot 10^{-10}$ a, and beginning with R ∼ 48 000 ⟶ 50 000 km a clear increase of negative collector currents is observed; they reach $11 \cdot 10^{-10}$ a for R ∼ 65 000 ⟶ 70 000 km. It must also be noted that over the portion from 55 000 to 75 000 km (during about 1.5 hours flight), only negative currents were registered in all four traps. Since the traps were disposed at summits of the tetrahedron inscribed in the sphere, and though at least one of them was at a given moment in the shade, the simultaneous presence of negative collector currents may be explained only by container hitting over that portion an electron flux with energies exceeding 200 eV (such electrons are are capable of overcoming the decelerating field of the inner grid and reach into the collector). Since these fluxes have not been registered by instruments designed for cosmic ray measurement (the minimum energy of registered particles being about 20 keV), and installed in the same container, the upper energy threshold for these electrons is 20 keV.
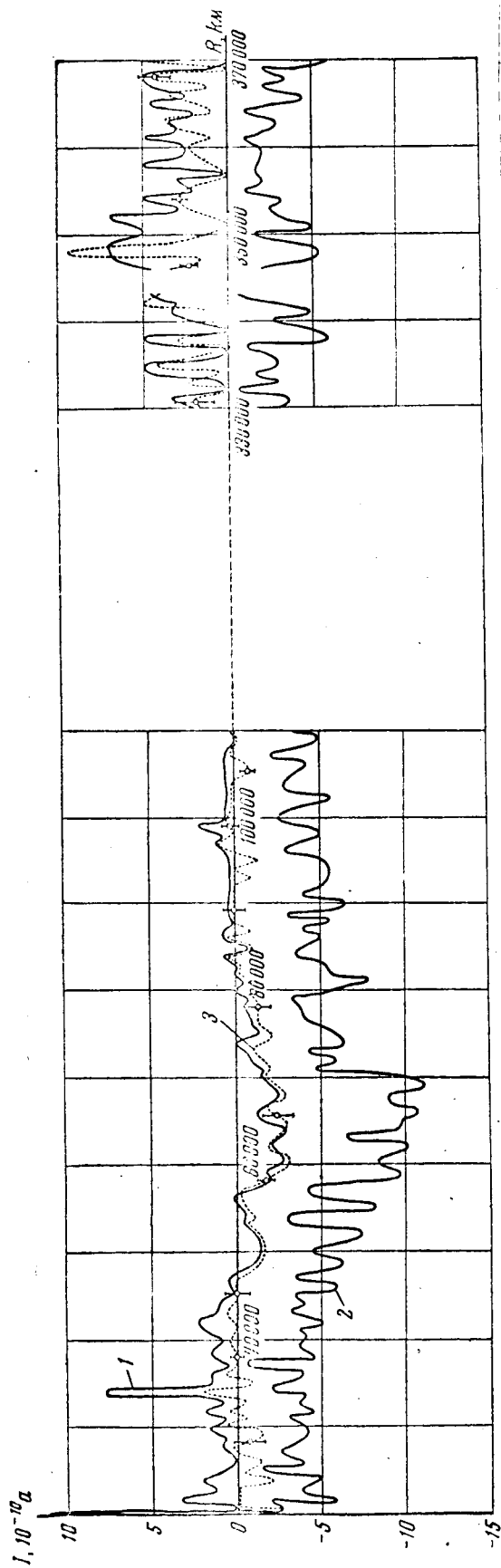
Fig. 7. Measurement of collector currents in the ttaps on the 2nd cosmic rocket

1 and 2 – upper and lower boundary of collector currents in traps with $g^2 = -10$, -5 and 0 V
3 – upper boundary of collector currents in the trap with $g^2 = + 15$ V.

Experiments with traps similarly disposed in the second cosmic rocket, carried out in the electron accelerator, have shown that at trap irradiation by electron flux with energies from 200 eV to 40 keV, the current in the collector circuit may be less than the quantity determined by flux incident on the collector, by no more than 2 ÷ 3 times (as a result of electron reflection from the collector, and at the expense of the most energetic part of secondary electrons, not being suppressed by the decelerating field of the second grid). When accounting this circumstance, the estimate of the density of electron fluxes registered over the portion from 50 000 to 75 000 km from the Earth gives $N \approx (1.5 \div 4)\, 10^{8}\, cm^{-2}.\, sec^{-1}$.

These measurements, corroborated by the data of the first cosmic rocket, provide a basis to assert about the existence of an outermost belt of charged particles, surrounding the Earth and disposed beyond the radiation belts. The boundaries of this belt pass along the lines of force of the geomagnetic field, similarly to boundaries of Earth's radiation belts. (see Fig. 8). It is formed of particles, whose energies are insufficient to be perceived by the indicators designed to register particles in the radiation belts.
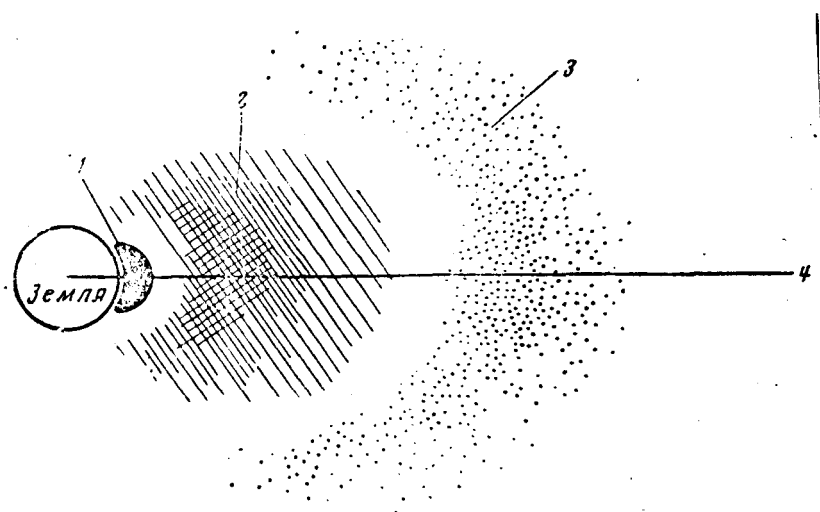

Fig. 8. Scheme showing the disposition of belts
of charged particles.

1 — "inner" radiation belt ; 2 — "outer" radiation belt ;
3 — outermost belt ; 4 — geomagnetic equator.

Communications concerning the detection of electron fluxes
at distances of 50 → 74 000 km from the surface of the Earth and
the third radiation belt are included in references [2 – 5].

Comparison of the results of magnetic measurements carried
out on the American satellite Explorer VI in August 1959 and on the
cosmic rocket Pioneer V in March 1960 led the authors [6] of these
experiments to the representation on the existence of a ring current
surrounding the Earth, with a total current of $5 \cdot 10^6$ a. The authors
referred-to reached the conclusion that the toroidal model with a
constant current density in cross-section, and a circular cross-section
with a center at the distance of ten Earth radii ($10 R_E$) from the cen-
ter of the Earth (thus about 58,000 km from the Earth's surface)
and with a radius equal to $3 R_E$ (this about 19 000 km)agree well with
the experimental data of magnetic measurements.

The first two Soviet cosmic rockets crossed the geomagnetic
equator at a distance of about 60 000 km from the Earth's surface,
thus in the region where the center of the ring current is located,
and whose existence follows from the data of American magnetic mea-
surements. As may be seen from Fig. 7, the center of the region in
which electron fluxes with $E_e > 200$ eV were detected during the
flight of the second cosmic rocket, is located at a height of the
order of 60 → 65 000 km from the surface of the Earth, i. e. near the
center of the ring current computed according to Explorer VI data.
The maximum of electron fluxes' density lies in a region stretching
20 000 km (at 55 to 75 000 km height), while the length of the whole
region where electron fluxes are detected, is about 40 000 km, which
is very close to the diameter of the ring current ($2a = 6 R_E$),
computed in the work of reference [6].

The current's density (or of electron flux) increases as
it gets nearer to the center of the region of their existence, and
decreases near the region's boundaries, as this results from the
experiments with charged particle traps, while in reference [6] it
was taken invariable along the current ring section. However it is

quite clear, and it is indicated in [6], that such model of ring current was accepted only for the simplification of calculations. One may suppose, that the current creating magnetic effects, registered on American probes, occurs as a consequence of magnetic field inhomogeneity and it really constitutes a drift current of electrons in the outermost belt.

The quantitative comparison of the density of electron fluxes by means of traps with the current density in the "ring current" computed in [6], is difficult on account of the fact that the determination of a drift current in a plasma in which the specfic kinetic energy of a particle W_k is close to the specific energy of a magnetic field W_H is still an unresolved problem. Precisely such a case is observed in the outermost belt : This is apparent from the fact that magnetic field disturbances are commensurate with the magnetic field itself. If however we make use of standard formulae for a drift current (strictly speaking only valid for $W_H \gg W_k$), we may see from [5], that the value of electron fluxes registered by the traps may be intelligently made to agree well with the value of geomagnetic field disturbances, revealed in the very same region in reference [6].

The experiments with charged particle traps in regions remote from the Earth by distances of the order of $50 \div 80\,000$ km, and the data on magnetic measurements at same distances [6] are evidence that the outermost belt of charged particles around the Earth is not a sporadic phenomenon, but a constant formation. The problem of subsequent investigations of that belt, is making more precise the knowledge of its properties, and in particular of its variability in time and space, and also of the energetic spectrun of electrons creating the effects, that were revealed through the American and Soviet experiments.

3. SOLAR CORPUSCULAR STREAMS. IONIZED INTERPLANETARY GAS.

It is clearly visible in the same Fig. 7, that positive collector currents were registered in all traps over the last portion of the trajectory of the second cosmic rocket (the beginning of which corresponds to the resuming of radiocommunication with the container at $R \sim 255\,000$ km, on 13 September 1959, at 19 02 hrs Moscow time). This includes also the trap with a positive potential in the outer grid, $\varphi_{g2} = 15\,V$. The greatest magnitudes of the current are identical in all four traps. During that portion of the flight the geomagnetic disturbances on Earth are characterized by the K — index, equal to 5 [7, 8]. Therefore, first were registered fluxes of positive ions from solar corpuscules (the electrons of solar corpuscular streams do not carry enough energy to overcome the decelerating field induced by the trap's inner grid). The positive collector current $I_k > (5 \div 7)\,10^{-10}\,a$ corresponds to the density of the flux of corpuscules — about $2 \cdot 10^8\,cm^{-2}\,sec^{-1}$.

Earlier, registered were in the four traps during 11 hours of container's flight (from $R \sim 80\,000$ km to $R \sim 190\,000$ km) currents whose values oscillated between the negative values reaching $(5 \div 6) \cdot 10^{-10}\,a$, and zero (obviously corresponding to trap location in the shady side of the container). During that time, the geomagnetic disturbances were characterized by K-indices, successively taking the values 4, 2 and 2 [7, 8].

At time of positive current appearance over the last stretch of the trajectory, negative currents did not disappear, and their magnitude decreased insignificantly. This attests that the orientation of the trap, for which the the incident flow of corpuscules reaches its maximum value, does not coincide with the orientation at which the reverse current reaches the maximum, the latter being induced by photoemission from the inner grid of the trap (for in opposite case no negative currents could have been observed).

Cases of absence of positive currents $I_k > 10^{-10}$ a were
more than once registered during the flight of the AIS launched
with the aid of the third cosmic rocket. Thus, for instance, posi-
tive currents were totally absent in two traps with potentials in
the outer grids $\varphi_{g2} = +25$ V and $\varphi_{g2} = -10$ V during a half hour
telemetring of data, having started at 17 30 hours Moscow time on
8 October 1959 at the distance of the order of 449 000 km from the
Earth. During that session and in the following three hours the
geomagnetic disturbances were characterized by a K-index equal to 2.

It is interesting to note the cases of registration of more
significant corpuscular streams than during the flight of the second
cosmic rocket. Such are the observations made during the flights of
the third and fourth cosmic rockets.

Saw-like pulses of voltage were fed with a period of about
20 seconds several times during four-minute intervals to two traps
of the four installed aboard the AIS of the 3rd cosmic rocket.
They were superimposed to the constant voltage minus 5 volts relati-
ve to the frame of the container. As a result, potentials φ_{g2} of
the outer grids relative to the frame varied from +9 to −19 V.
The graphs of collector current variations of both traps during one
such interval (14 52 Moscow time on 4 October 1959 at $R \sim 126\,000$ km
from the Earth) are brought out in Fig. 9 (next page). To construct
these graphs, 240 points were utilized, that were disposed in a
known order between recordings of alternate voltage in outer grids
and the registrations of traps' collector currents. Dashes indicate
the absence of data on measured values of currents.

It may be seen from Fig. 9 how well expressed is the effect
of AIS rotation, expressed in alternated increase and decrease of
positive collector currents of both traps (with a 150 sec period).
At the same time, it is quite clear that the variation of traps' col-
lector currents is not connected with that of their outer grids' poten-
tials.

This apparently is explained by the fact that the energies of positive particles creating collector currents, are sufficiently great, and the variations of grid potentials by about 30 V are immaterial. The intensity of corpuscule flux in this case may be estimated as being $4 \cdot 10^8 \, cm^{-2} \, sec^{-1}$. Let us note that the indicated determination is related to the time interval from 14 54 to 14 58 hours Moscow time. The characteristics of geomagnetic disturbances (K-indices) are the following un the closest time intervals :

in the interval from 12 00 to 15 00 (Moscow t.) K = 4.
in the interval from 15 00 to 18 00 hrs — K = 6.

From our viewpoint the density measusurements of corpuscular flux density carried out during the flight of the fourth cosmic rocket (Venus probe of 12 Feb.1961) offer a significant interest. This is the only such case to-date, whereby measurements were conducted by means of two traps constantly oriented towards the Sun, and whose outer grid potentials were $\varphi_{g2} = + 50$ V and $\varphi_{g2} = 0$ V.

Presented are in Fig.10 collector current graphs* during the three telemetering sessions, the transmittee results of which are given in the following Table.

Number of session	Date Feb.1961	Beginning of the session Moscow time	Distance from the Earth, km
1	12	06 45	26 400
2	12	14 25	165 000
3	17	14 35	1 890 000

* The graph demonstrated during the Symposium was constructed according to data of preliminary processing. Fig.10 offers a corrected graph.
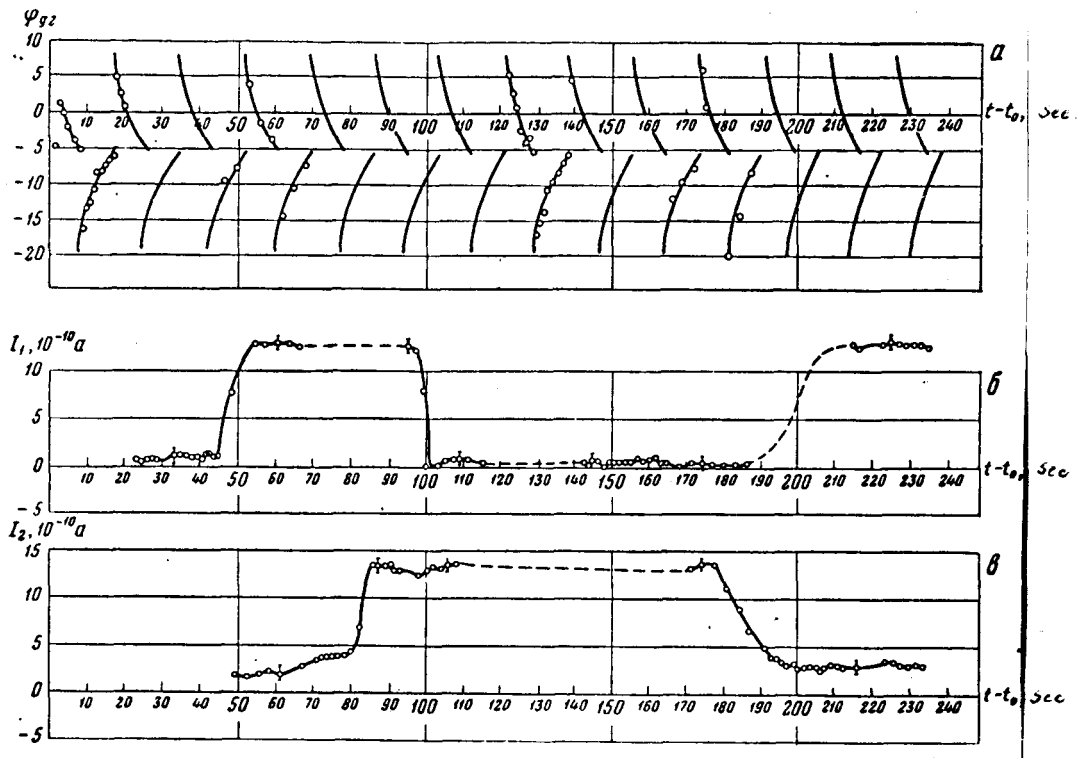
Fig. 9. Current variations in the traps as a result of rotation
of 3rd cosmic rocket's AIS :

a — periodical variation of φ_{g2} given by the instruments

δ, θ — collector currents in traps 1 and 2.

It may be seen from Fig. 10 (next page) that first, at time
of our experiments with charged particle traps, the collector
current modulation, caused by container rotation is absent.
As may be seen from the graphs, currents of both traps oscillated
near the zero values during the first session. During the second
session identical positive currents $I_K \sim 5 \cdot 10^{-10}$ a were register-
ed in both traps.

It must be borne in mind that the amplifier of the trap's
collector current, the outer grid potential being $\varphi_{g2} = 0$, had
a characteristic consisting of two linear portions. The steepness
of the upper portion was comparatively small, the maximum measured
current having been close to $8 \cdot 10^{-8}$ a. The collector current ampli-
fier of the trap with $\varphi_{g2} = 50$ V had a characteristic close to
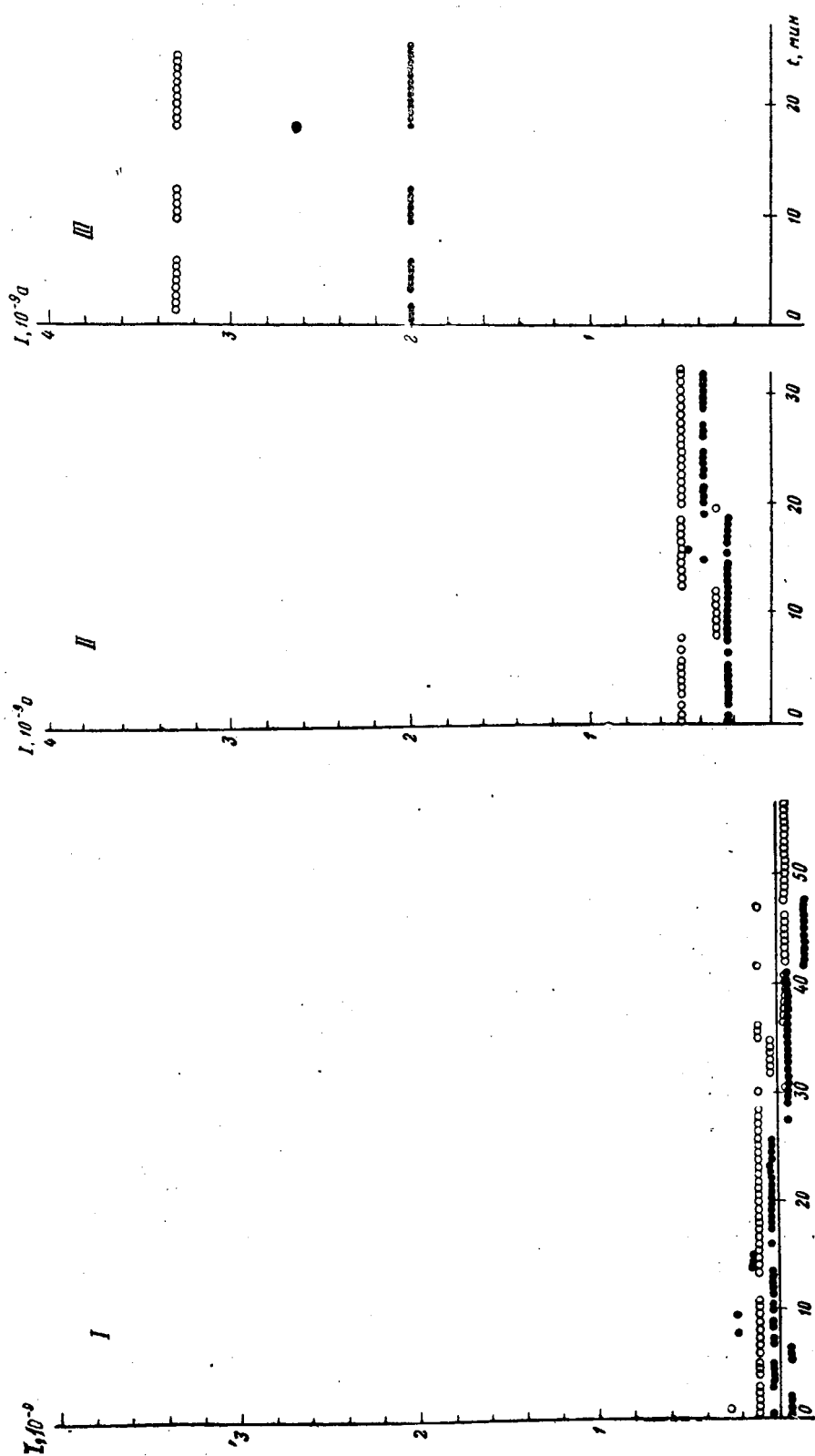linear, and the maximum measured current was of $2 \cdot 10^{-9}$ a.

Fig.10. Collector currents measured during the three transmission sessions from
the AIS of th fourth cosmic rocket (12 Feb.1961 –Venus probe)

I, II, III – numbers of sessions. Black dots – measurements in the trap with
φ_{g2}= 50 V., circles – measurements in the trap with φ_{g2} = 0.

It is seen in Fig.10 that during the third session of data telemetering, greater collector positive currents were registered in both traps than at any time before. These currents correspond to the density of the flux of positive corpuscles $N \approx 10^9 \, cm^{-2} \, sec^{-1}$. It is important noting that at about 12 00 hours Moscow time a commencement of a magnetic storm was registered on Earth with a perturbation amplitude $H \sim 100$.

Thus, corpuscular stream observations in the interplanetary space gave for the first time informations necessary for the establishment of quantitative relationships between the density of the solar corpuscular stream and the intensity of geomagnetic disturbances it induces.

The informations expounded may be utilized for the estimate of possible concentrations of the supposedly existing stationary interplanetary ionized gas. We may in particular utilize for that purpose the graphs brought out in Fig.9.

In estimating the concentration of stationary ionized gas, which is devoid of directed velocity relative to the Sun, one of the difficulties stems from the fact that at small gas concentrations, the density of photoelectron flux from container's surface begins to exceed the density of the flux of electrons from the surrounding medium. As a result, the container acquires a positive potential relative to the medium, and the concentration of positive ions near it drops by comparison with their concentration in the unperturbed region. In spite of the fact that beyond the geomagnetic field the interplanetary ionized gas has a significant directed velocity relative to the container (equal to about the orbital velocity of the Earth), the proton energy in the gas flow, incident upon the container, is only about 5 eV, and for a positive container's potential of a few volts, such protons may fully decelerate.

As was already noted, it is clearly visible from the graphs of Fig. 9, that the potential variations in the outer grids of the traps by about 30 V (from +9 V to − 19 V) in no way influence the magnitude of the collector current. Since at the same time potentials of traps' outer grids relative to the surrounding neutral medium must necessarily pass through zero and even negative values, the fact itself of absence of effect on the measured currents of such significant variations of the potential (by comparison with the possible energy of protons) is evidence of smallness of stationary gas concentration. Assuming that at some time interval part corresponding to Fig. 9, even if one of the two traps occupies an optimum position relative to the stationary gas flow (i. e. its orientation coincides with the velocity vector v_o of container's orbital motion around the Sun), and considering the moment when the potential of its outer grid relative to the medium is near zero (we then estimate

$$v_i = \sqrt{\frac{2kT_i}{m_i}} \ll v_0,$$

which may only overrate the estimate of the concentration of ions of stationary gas n_{io}), we have

$$n_{io} \leq \frac{I_{min}}{S\alpha e v_0} \quad ,$$

where I_{min} is the minimum variation of the collector current, that may be reliably computed ($I_{min} = 2 \cdot 10^{-10}$a); S — the traps' cross-section in cm^2; $v_0 \approx 3 \cdot 10^6$ cm sec^{-1}; e is the charge of the electron; α is the aggregate transparency coefficient of trap's grids. The substitution of numerical values gives

$$n_{io} \approx 1.5 \text{ cm}^{-3} \quad .$$

In 1958 — 1959, when experiments with charged particle traps were in preparation and had begun, it was generally admitted that in the region of the orbit of the Earth the concentration of interplanetary ionized gas was of the order of $5 \cdot 10^2 \div 10^3$ cm^{-3}. Such a picture was based on one hand on Siedentopf and Behr experiments [9] on observations of polarized zodiacal light, and on the Storey experiments consisting of atmospheric whistler observations [10] — on the other. The latter provided fatuitiously an estimate of electron concentration near that of Siedentopf and Behr. At present, and owing to experiments with traps we know that the Storey estimate, related to the height of the order of 11 000 km, was correct, but it characterized the peripheral region of the Earth's gas shell, stretching to about 20 000 km, and not the interplanetary medium. The estimate of interplanetary gas concentration, obtained on the basis of current measurements in charged particle traps on cosmic rockets, was unexpected and it diverged from the existing representations and theories (see for example the Chapman theory [11], who considers the interplanetary gas as the extension of the solar corona with a concentration of the order of 10^3 cm^{-3} and temperature $T \sim 10^5$ °K near the Earth).

At the same time it should be noted, that even as far back as in 1957 — 1958, Van de Hulst [12] and Fesenkov [13] have shown that the polarization of zodiacal light, scattered in dust particles, may be high. Lately, several works have appeared in the late 1960 and early 1961, from which it appears that the concentration of interplanetary gas is quite small. These are papers by Blackwell [14] and Pope [15], respectively on zodiacal light and on the observation of atmospheric whistlers of the "noses" type.

In conclusion something should be said about the prespective of further experiments with charged particle traps in the interplanetary medium. In the experiments with traps set up so far, the measurement sensitivity was limited by the reverse corrent created

by the photoelectrons from the inner grid. The presence of this current often even hindered the interpretation of results. At present preparations are drawing to an end of two variants of devices with traps (also of half-sphere type) in which particle flux modulation will be utilized, these particles emerging from the surrounding medium without modulation of photoelectron current. The new devices are designed to study the eneregetic spectrum of electrons in the outermost radiation belt surrounding the Earth, the energetic spectrum of solar corpuscules, and also to attempt the detection of stationary interplanetary gas (even against the background of corpuscular streams). We learned with great interest from the work [16] published in the USA, that measurements by means of traps in the interplanetary space are also being prepared there along lines similar to ours. For the study of planetary ionospheres, three-electrode traps will apparently find their application with feeding saw-like voltages to their outer grids. The results of experiments described here and in [1] allow to consider that charged particle traps on cosmic rockets will play an important part in the study of interplanetary space, of other planets' atmospheres and of solar activity.

Besides the author of this report, the following persons participated in the preparation and conducting of experiments and in the processing of results : V. V. Bezrukikh, V. D. Ozerov and R. E. Rybchinskiy, all collaborators of the Radiotechnical Institute of the USSR Academy of Sciences. As to the interpretation of the part of the work having bearing to the outermost belt of charged particles, Prof. I. S. Shklovskiy, V. G. Kurt, V. I. Moroz of the Astronomical Institute in the name of Shternberg have contributed. Finally, Prof. Rytov participated in the comparison and coordination of the results of measurements by meass of traps with the American magnetic measurements in the region of the outermost belt.

****** THE END ******